

The Apparent Projection of Stars upon the Bright Limb of the Moon at Occultation, and similar Phenomena. By Professor George Davidson, Ph.D., Sc.D., U.S. Coast and Geodetic Survey.

(Communicated by the President.)

In the Observatory for February 1890, upon p. 72, the Astronomer Royal is reported to have called attention to an occultation of a star by the Moon, among the occultations of 1889 at the Royal Observatory, that presented matter of "interest."

On September 16 Mr. Turner observed the occultation of ζ Tauri by the bright limb of the Moon, with the Lassell reflector of 24 inches, and Mr. Lewis with a refractor of three and three-fourths inches. Mr. Turner noted "no projection: disappeared instantaneously at bright limb." Mr. Lewis noted that "the star touched the limb of the Moon five seconds before the observation, and was slightly inside the limb. It appeared as a brilliant spot in the Moon, and disappeared suddenly at the time given above." On p. 69, Mr. Ranyard says that "in the case of Jupiter there are cases . . . where one or two stars have apparently been seen through the limb of the planet. There are such a number of these observations that we cannot doubt that the planets have not a sharp limb, they seem to be surrounded by an atmosphere of great depth, or rather a gaseous envelope in which clouds or dusty matter float in irregular masses."

I have frequently seen this question brought forward with such unsatisfactory explanations that perhaps you will grant me the opportunity to present a few instances from my own experience, and my explanation of the phenomenon. My experience extends through forty-seven years as an observer, and to elevations reaching ten and eleven thousand feet above the sea.

In 1848 or 1849, during daylight, I observed the occultation of a *Scorpii* by the bright limb of the Moon, using a transit telescope with probably two and one-half inches aperture and low power. The red star touched the bright limb and I noted the time mentally, but as the star did not disappear I continued the watch for about two and one-half seconds longer, when the red star was unmistakably within the apparent limb. It disappeared instantaneously, and I noted that time also. I at once submitted the case to my chief, who said the time of disappearance was the true time of the occultation, but gave no explanation. I then submitted the observation to Superintendent Bache, who wrote to either Herschel or Airy on the subject. The reply was that he personally had never observed the phenomenon, but that there were some similar cases on record. However, he gave no explanation.

In the Survey of Admiralty Inlet and Puget Sound, about 1855, I again observed the occultation of a *Scorpii* by the bright

limb of the Moon at night, with phenomenon similar to that of 1848 or 1849. I probably used a three-inch Fraunhofer and moderate power.

My continuous geodetic and astronomical duties have long since led me to a solution of these and many somewhat similar appearances. *A spurious limb of the Moon is formed by the unsteadiness of our own atmosphere immediately surrounding the station of the observer.* This unsteadiness of the atmosphere throws the disc of the Moon into irregular vibrations of small amplitude and short duration ; and from the same cause the star is not sharply defined as a steady point, but is seen fuzzy, flickering, and unsteady, with a bright nucleus.

The star approaches the actual limb of the Moon and both partake of the unsteadiness ; but if the nucleus of the star be large and coloured, the impression of its image upon the eye is more intense than the image of the whitish, confused, spurious edge of the Moon, even when the former is inside the latter. The action of the eye is selective, and the effort is greater with the less favourable condition of a white star. There is no effort and no need of selection to receive an impression of the image of the Moon's limb, although it may be seen with high power.

The impression of the star's image is therefore continuous within the range of amplitude of the excursions of the disc of the Moon, but is instantly lost when the limit of range is reached and the actual limb of the Moon passes over the star.

With a large, coloured star the phenomenon is unmistakable ; with a white star it may be somewhat in doubt ; with a small white star it will very probably not be noted.

I have witnessed similar phenomena when the satellites of *Jupiter* have been occulted by the planet. In this case my fellow-observer with the smaller telescope, say of two and one-half or three inches, loses the satellite much sooner than I observe its disappearance in my 6·4-inch Clark equatoreal ; and this will always occur with the larger objective and the higher power. When the atmosphere is steady and the limb of the planet sharply defined the above phenomenon is absent. When the atmosphere is remarkably steady the bright limb of the Moon is seen with all its serrations and irregularities, and then the star about to be occulted, whether large or small, coloured or white, apparently approaches it and instantly disappears at the point of contact. Under such conditions it never enters upon the limb of the Moon.

In geodetic work the phenomenon of false extension of the image of the heliotrope signal is the same as that for the false enlargement of the disc of the Sun, the Moon, *Jupiter*, or the image of a star. In the high Sierras of California, at 10,600 feet elevation, I have observed upon the minute images of heliotropes that did not measure one second of arc in diameter in the telescope, and were distant 120 to 160 miles to the north-west, where the wonderfully clear sky and the steady atmosphere after a

storm gave astonishing sharpness, steadiness, and nearness to all objects; and turning to the signals down to leeward the images of these heliotropes would range to thirty seconds of arc in diameter, and be remarkably diffuse, irregular, and unsteady. On a certain line of the triangulation in the coast range of mountains, where several mountain ridges and intervening valleys were crossed by the line of sight, and where the cold ocean air irruption, through the Karquines Strait, added tenfold confusion, the heliotrope image from Mount Diablo was like the waving flame from the stack of a smelting furnace, and sometimes exceeded sixty seconds of arc in diameter with its direction abnormal. When the air that the ray of light passed through became of uniform temperature the image was steady, small, and starlike, and its direction normal.

We meet with phenomena of similar character in observing upon all geodetic signals, especially in the less elevated regions; "poles" are only seen sharply and clearly defined when the atmosphere is supremely clear and still, and then at enormous distances. As a rule they are apparently broadened several times their normal width by the unsteadiness of the atmosphere.

It is this unsteadiness of the atmosphere, *and this alone*, which presents to the observer the phenomena of the "black drop," "ligament," &c., in the transits of *Venus* and *Mercury*; and the "Baily's beads," &c., in total solar eclipses.

When the atmosphere is fairly clear and remarkably steady, so that there is little or no irradiation from the disc of *Jupiter*, and necessarily no unsteadiness in the appearance of the satellites, I have been able to distinguish with the naked eye two satellites as one, when they were near each other. I have made public record of such occurrences; and at one station in the mountains all the members of my party saw the phenomenon. Under similar conditions of atmospheric serenity, but with the advantage of greater elevation, one or more of the professors from the United States Naval Observatory, then in the mountains of Colorado to observe the total solar eclipse of 1878, saw three satellites of *Jupiter* with the unassisted eye, the fourth being behind the planet. When these favourable conditions exist the occultation of a satellite by the planet is very satisfactorily observed.

In years of experience upon the Pacific Coast of the United States in observing lunar transits, I learned to expect wild results when a spurious bright limb of the Moon was observed, the resulting longitude being affected as if the diameter of the Moon were too great. At times, when the vibration or undulation of the disc of the Moon was not rapid, the sharp limb could be observed even with a faint spurious outline beyond it. Within the last two months my party has had a case of spurious disc from excessive diffusiveness, with a predicted error in the resulting longitude that was verified.

In my observations of the last transit of *Venus*, at 5,691 feet above the sea and 1,600 feet above the arid Jornada del Muerte,

there were at one time occasional shiverings of the discs of the Sun and planet from slight tremulousness of the atmosphere, but the eye was not confused, as would have been the case if the discs had been ill-defined and unsteady by excessive vibration. In the first case the eye could and did select its opportunity for measurement. At other stations for the same transit the atmospheric disturbance distorted the appearance of the fine crescent of coronal light apparently surrounding part of the disc of *Venus* when the planet was partially off the Sun's limb; but at Cerro Roblero the steadiness of the atmosphere at the time of the last exhibition of this phase permitted us to see the long, thin, white crescent, as fine and sharp and regular as if cut by a graver, die away in excessive minuteness.

In conclusion, I may mention that I have been fortunate in my observations of the transits of *Venus* and of *Mercury* never to have had the exhibition of "ligament" or "black drop"; and in solar eclipses to have never seen "Baily's beads," &c. In my experience the occurrence of supreme steadiness of the atmosphere is very rare indeed, but has happened oftener at great elevations of mountain peaks, and the narrow crest-line of a mountain-range during the winter season of this coast.

The Jovian Evection. By E. Nevill.

In the year 1876, whilst discussing the observations of the Moon made at Greenwich and Washington during the years 1862-74, Professor Newcomb discovered a new inequality in the motion of the Moon in longitude.

This inequality was subsequently shown to arise from the disturbing action of the planet *Jupiter*, and to be the term in the perturbations produced by that planet which corresponds to the well-known *evection* due to the disturbing action of the Sun. Hence the name—the *Jovian Evection*.

In the *Memoirs* (vol. xxix., 1861) Sir G. Airy has given the results obtained by him from a discussion of the Greenwich lunar observations during the period 1750-1851, and among other results he has deduced the corrections to the adopted theory having for argument the sine and the cosine of the Moon's mean anomaly. He gives the value deduced for the coefficient of these terms for twenty-one consecutive periods of about nine years each. These coefficients are tabulated on pp. 12 and 14, under the heads—values of S and of T respectively.

From a discussion of these values Sir G. Airy deduces the existence of apparent inequalities in the longitude of the Moon of the form—

$$\begin{aligned} & + 0''\cdot47 \sin(\alpha + B) \\ & - 0''\cdot17 \cos(\alpha + B) \\ & - 1''\cdot12 \sin(\alpha - B) \\ & + 0''\cdot37 \cos(\alpha - B) \end{aligned}$$